

WHAT IS CLAIMED IS:

- 5 1. A high power ultrasonic transducer comprising a housing having a predetermined geometry, means carried by the housing for providing power in excess of three kilowatts including a transducer having one or more active elements made from a magnetostrictive material and means for producing an electromagnetic field which extends through at least a portion of the one or more active elements, the one or more active elements each changeable between a first shape when in the absence of the electromagnetic field and a second shape when in the presence of the electromagnetic field, means for providing an electrical signal to the means for producing an electromagnetic field and an acoustic element connected to the transducer for channeling ultrasonic energy to perform work.
- 10 2. The ultrasonic transducer of Claim 1 wherein there is one cylindrically-shaped active element and wherein the means for producing an electromagnetic field is a coil made from conductive material concentrically disposed about the active element.
- 15 3. The ultrasonic transducer of Claim 2 further comprising magnetic means for biasing the active element.
- 20 4. The ultrasonic transducer of Claim 3 wherein the magnetic means includes tubular magnetic means concentrically disposed about the cylindrical element, the tubular magnetic means having first and second opposite end portions and a central portion between the first and second end portions, the first and second end portions having a radial thickness and the central portion having a radial thickness which is less than the radial thickness of the end portions for producing a substantially uniform bias over the length of the cylindrical element.

5. The ultrasonic transducer of Claim 4 wherein the first and second end portions having an inner diameter and the central portion has an inner diameter which is less than the inner diameter of the end portions.

5 6. The ultrasonic transducer of Claim 5 wherein the first and second end portions are first and second annular members and wherein the central portion is a third annular member disposed between the first and second annular members.

10 7. The ultrasonic transducer of Claim 2 wherein the cylindrical element has first and second opposite ends, first and second flux return elements carried by the housing adjacent the first and second ends of the cylindrical element for capturing magnetic flux through the cylindrical element.

8. The ultrasonic transducer of Claim 7 wherein the first and second flux return elements are first and second disk-like elements made from a material having an electrical resistivity ranging from about 0.01 to 50 ohm-cm and a magnetic saturation flux density ranging from about 12,000 to 15,000 gauss.

15 9. The ultrasonic transducer of Claim 8 wherein the material of the first and second disk-like elements is an alloy having about 50% iron and 50% nickel.

10. The ultrasonic transducer of Claim 1 further comprising magnetic means for biasing the active element.

20 11. The ultrasonic transducer of Claim 1 wherein the acoustic element is mounted on the transducer and is made from a material having a quarter resonant wavelength, the acoustic element having a length equal to the quarter resonant wavelength of the material.

12. The ultrasonic transducer of Claim 1 wherein the acoustic element is made from an acoustic metal.

13. The ultrasonic transducer of Claim 12 wherein the acoustic element is made from a magnesium alloy.

5 14. The ultrasonic transducer of Claim 1 for use with a cooling fluid, the transducer including means for providing a passageway about the transducer adapted to receive the cooling fluid.

15. The ultrasonic transducer of Claim 14 wherein the means for providing a passageway is formed from a material which is an electrical insulator.

10 16. The ultrasonic transducer of Claim 15 wherein the material has a thermal conductivity greater than about one (1) W/m-K.

17. The ultrasonic transducer of Claim 14 wherein the means for providing a passageway is formed from hot pressed boron nitride.

15 18. The ultrasonic transducer of Claim 14 wherein the means for providing a passageway includes means for forming a helical passageway within the transducer.

20 19. A high power ultrasonic transducer comprising a housing having a predetermined geometry, means carried by the housing for providing power in excess of three kilowatts including a transducer having a cylindrical actuation element made from a magnetostrictive material and a coil made from electrically conductive wire concentrically disposed about the cylindrical element for producing an electromagnetic field that extends through at least a portion of the cylindrical element, the cylindrical element changeable between a first shape when in the absence of the magnetic field and a second shape when in

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the presence of the magnetic field, means for supplying an electrical signal to the coil and an acoustic element connected to the transducer for vibrating at an ultrasonic frequency in response to the transducer for performing work.

20. The ultrasonic transducer of Claim 19 further comprising means for actively cooling the transducer which includes means for forming a fluid-carrying helical passageway which extends about the transducer.

21. The ultrasonic transducer of Claim 20 wherein the means for forming a fluid-carrying helical passageway is made from an electrical insulator.

22. The ultrasonic transducer of Claim 20 wherein the means for forming a fluid-carrying helical passageway extends through the cylindrical element.

23. The ultrasonic transducer of Claim 20 wherein the means for forming a fluid-carrying helical passageway extends through the cylindrical element.

24. A high power ultrasonic transducer comprising a housing having a predetermined geometry, a transducer having a rod-like element made from a magnetostrictive material and a coil made from electrically conductive wire concentrically disposed about the rod-like element changeable between a first shape when in the absence of the magnetic field and a second shape when in the presence of the magnetic field, tubular magnetic means concentrically disposed about the coil for biasing the rod-like element and having first and second opposite end portions and a central portion between the first and second end portions, the first and second end portions having a radial thickness which is less than the radial thickness of the end portions, means for supplying a sinusoidal electrical signal to the coil, means for supplying a sinusoidal electrical signal to the coil, means for actively cooling the transducer which includes means made from an electrical insulator for forming a fluid-carrying helical passageway which extends about the transducer, the rod-like

element having first and second ends, first and second flux return means carried by the housing adjacent the first and second ends of the rod-like element for capturing magnetic flux through the rod-like element and an acoustic element connected to the transducer for vibrating at an ultrasonic frequency in response to the transducer for producing useable work.

25. The ultrasonic transducer of Claim 24 wherein the first and second flux return means are adjacent the first and second end portions of the tubular magnetic means.

26. The ultrasonic transducer of Claim 24 wherein the first and second flux return means are adjacent the first and second end portions of the tubular magnetic means are made from a material having an electrical resistivity ranging from 0.01 to 50 ohm-cm and a magnetic saturation flux density ranging from 12,000 to 15,000 gauss.

27. The ultrasonic transducer of Claim 26 wherein the means for forming a fluid-carrying helical passageway is a made from a material selected from the group consisting of boron nitride, aluminum nitride, alumina, silicon carbide, boron carbide, titanium debarred, tungsten carbide, silicon nitride and spinel.

28. The ultrasonic transducer of Claim 25 wherein the means for forming a fluid-carrying helical passageway is made from a material selected from the group consisting of boron nitride, aluminum nitride, alumina, silicon carbide, boron carbide, titanium diboride, tungsten carbide, silicon nitride, spinel, pyrolitic graphite, pyrolitic boron nitride, beryllia, graphite and silicon.

29. A magnetostrictive actuator comprising an active element made from a magnetostrictive material having first and second ends, the magnetostrictive element changeable from a first shape to a second shape in the presence of a magnetic field, means for producing a magnetic field which extends through at least a portion of the active element

and first and second flux return elements adjacent to the first and second ends of the magnetostrictive element for capturing magnetic flux produced by said means and directing the magnetic flux through the magnetostrictive element.

30. An actuator as in Claim 29 wherein the means for producing a magnetic field
5 includes a coil concentrically disposed about the magnetostrictive element.

31. An actuator as in Claim 29 further comprising a permanent magnet
concentrically disposed about the magnetostrictive element for providing a Dc magnetic bias
to the magnetostrictive element, the permanent magnet having first and second ends, the
first and second flux return elements adjacent the first and second ends of the permanent
10 magnet for capturing magnetic flux produced by the permanent magnet and directing said
flux through the magnetostrictive element.

32. An ultrasonic transducer comprising:
a plurality of sub-motors each containing an active element made from a smart
material, wherein the sub-motors operate simultaneously to produce ultrasonic energy;
15 a cooling system connected to the transducers for cooling each active element, the
cooling system utilizing a phase change medium; and
a composite master wave-guide connected to the plurality of sub-motors, the master
wave-guide reactive to the ultrasonic energy from the sub-motors, wherein the master wave-
guide channels the ultrasonic energy to perform work.

- 20 33. The ultrasonic transducer of claim 32 wherein the composite master wave-
guide is comprised of a mode stabilizer and an output amplifier, further wherein the mode
stabilizer is made from a material having a speed of sound in excess of 6000 meters per
second.

34. The ultrasonic transducer of claim 32 wherein the ultrasonic transducer is capable of receiving up to 30 kW of power and outputting frequency in excess of 18 kHz on a continuous basis.

35. The ultrasonic transducer of claim 32 wherein the mode stabilizer and output amplifier comprise a single one-half wavelength master wave-guide, further wherein the transducer produces a one-full wavelength standing wave in one complete cycle.

36. The ultrasonic transducer of claim 35 wherein each active element is a one-half wavelength drive rod and the smart material is a magnetostrictive material.

37. The ultrasonic transducer of claim 36 wherein the smart material is TERFENOL or TERFENOL-D.

38. The ultrasonic transducer of claim 37 wherein the mode stabilizer is made from aluminum-beryllium, beryllium or a metal matrix alloy and the output amplifier is made from titanium or a titanium alloy.

39. The ultrasonic transducer of claim 38 wherein the phase change cooling medium exits the transducer as a fluid-vapor mixture, further wherein the mixture is reliquified in the single loop cooling system cooling system for use again in the transducer.

40. The ultrasonic transducer of claim 39 wherein the phase change cooling medium is a low-boiling hydrocarbon, ammonia or water.

41. The ultrasonic transducer of claim 32 further comprising:
a drive coil surrounding the plurality of sub-motors to provide an electromagnetic field; and

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a magnetic circuit surrounding the drive coil for biasing the active element.

42. The ultrasonic transducer of claim 41 wherein the drive coil has foil windings with a packing factor greater than about 85%.

43. The ultrasonic transducer of claim 41 wherein the magnetic circuit comprises
5 two magnetic rings, a plurality of cylindrical magnetic pieces located between the two magnetic rings, the flux concentrators, and each drive rod, further wherein the magnetic circuit is activated by providing a dc current.

44. The ultrasonic transducer of claim 43 wherein the active element in each sub-motor is split lengthwise to form a split active element having two sections.

45. The ultrasonic transducer of claim 44 wherein each sub-motor further
10 comprises:

a mode containment disk located between the two sections of the split active element to increase cooling of the split active element;

a prestress bolt having an opening through which coolant gas exits the sub-motor,
15 the prestress bolt located proximate to the split active element;

a wave-guide contiguous with the prestress bolt;

a gap located between the active element and the prestress bolt, wherein a ceramic
powder is placed into the gap to cool the split active element;

one or more flux concentrators, each located next to the split active element;

20 a preload disk located adjacent to one of the flux concentrators; and

a preload nut located adjacent to the preload disk.

46. The ultrasonic transducer of claim 45 wherein the preload nut, one flux concentrator and the preload disk comprise a reaction mass against which the split active element pushes.

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47. The ultrasonic transducer of claim 45 wherein the ceramic powder in the gap is boron nitride.

48. The ultrasonic transducer of claim 45 wherein the mode containment disk is a ceramic disk.

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49. The ultrasonic transducer of claim 45 comprising six sub-motors arranged in a ring pattern about a longitudinal axis of the transducer.

50. The ultrasonic transducer of claim 45 wherein the cooling system is a single loop cooling system.

10 51. The ultrasonic transducer of claim 45 wherein the master wave-guide has a tip, further wherein displacement of the master wave-guide tip is about 60 micrometers or more peak-to-peak.

52. The ultrasonic transducer of claim 45 wherein the transducer is used in sonochemical processes.

15 53. A method for channeling ultrasonic energy to perform work comprising: providing a plurality of sub-motors each containing an active element made from a smart material, wherein the sub-motors operate simultaneously to produce ultrasonic energy; cooling the sub-motors with a phase change fluid that flows through a cooling
20 system prior to entering the transducer and after exiting the transducer; and connecting the plurality of sub-motors to a composite master wave-guide, the master wave-guide reactive to the ultrasonic energy provided by the sub-motors.

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54. The method of claim 53 further comprising activating the transducer by providing power to a magnetic circuit surrounding the sub-motors, wherein the ultrasonic energy from the sub-motors is channeled to produce work.

5 55. The method of claim 53 further comprising exposing each active element to an electromagnetic field.

56. The method of claim 53 wherein high power work is provided in excess of ten (10) kW.

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10 57. The method of claim 53 wherein the electromagnetic field is provided by a coil made from a conductive material, the coil concentrically disposed about the plurality of sub-motors.

58. The method of claim 57 further comprising providing a dc current to bias the active element.

15 59. The method of claim 57 wherein two magnetic rings surround the coil, further wherein ferromagnetic pieces are arranged between the two magnetic rings for reducing system heating requirements.

60. The method of claim 53 wherein the active element is a one-half wavelength drive rod and the smart material is a magnetostrictive material.

61. The ultrasonic transducer of claim 60 wherein the smart material is TERFENOL or TERFENOL-D.

62. The method of claim 53 wherein the master wave-guide is comprised of a mode stabilizer and an output amplifier, further wherein the mode stabilizer is made from a material having a speed of sound in excess of 6000 meters per second.

63. The method of claim 53 further comprising:
5 splitting the active element into two sections to form a split active element;
guiding magnetic field intensity through the split active element with one or more flux concentrators;
cooling an inner diameter of each split active element with a silicon nitride or alumina disk; and
10 adding ceramic powder to a gap between the prestress bolt and the split active element to increase cooling of the split active element.

64. The method of claim 63 wherein power generating capability of the drive rod material is enhanced by about four times with the one or more flux concentrators.

65. The method of claim 63 further comprising:
flowing a liquid coolant into the transducer;
allowing the liquid coolant to hit a seal plate and splatter radially into openings in each sub-motor; and
venting a fluid-vapor mixture through an exhaust port in the transducer, the mixture
20 first exiting through an opening in the prestress bolt of each sub-motor.